FATIGUE CONSIDERATION IN DESIGN

OBJECTIVES AND SCOPE

In this module we will be discussing on design aspects related to fatigue failure, an important mode of failure in engineering components. Fatigue failure results mainly due to variable loading or more precisely due to cyclic variations in the applied loading or induced stresses So starting from the basic concepts of variable (non-static) loading, we will be discussing in detail how it leads to fatigue failure in components, what factors influence them, how to account them and finally how to design parts or components to resist failure by fatigue

WHAT IS FATIGUE?

Fatigue is a phenomenon associated with variable loading or more precisely to cyclic stressing or straining of a material. Just as we human beings get fatigue when a specific task is repeatedly performed, in a similar manner metallic components subjected to variable loading get fatigue, which leads to their premature failure under specific conditions.

WHAT IS FATIGUE LOADING?

Fatigue loading is primarily the type of loading which causes cyclic variations in the applied stress or strain on a component. Thus any variable loading is basically a fatigue loading.

Variable Loading

Variable loading results when the applied load or the induced stress on a component is not constant but changes with time i.e load or stress varies with time in some pattern. Most mechanical systems and devices consists moving or rotating components. When they are subjected to external loadings, the induced stresses are not constant even if the magnitude of the applied load remains invariant.

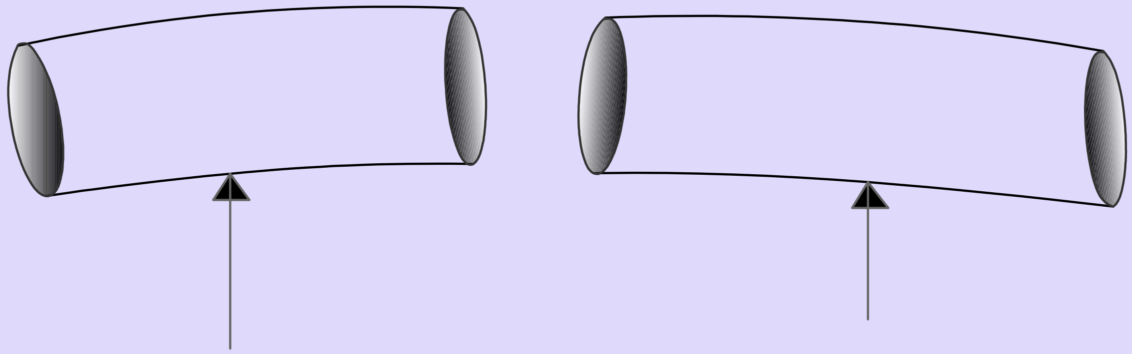
In reality most mechanical components experience variable loading due to

-Change in the magnitude of applied load Example: punching or shearing operations-

-Change in direction of load application Example: a connecting rod

-Change in point of load application Example: a rotating shaft

There are different types of fatigue/variable loading. The worst case of fatigue loading is the case known as *fully-reversible load*. One *cycle* of this type of loading occurs when a tensile stress of some value is applied to an unloaded part and then released, then a compressive stress of the same value is applied and released.



A rotating shaft with a bending load applied to it is a good example of fully reversible load. In order to visualize the fully-reversing nature of the load, picture the shaft in a fixed position (not rotating) but subjected to an applied bending load (as shown here). The outermost fibers on the shaft surface lying on the convex side of the deflection (upper surface in the picture) will be loaded in tension (upper green arrows), and the fibers on the opposite side will be loaded in compression (lower green arrows). Now, rotate the shaft 180° in its bearings, with the loads remaining the same. The shaft stress level is the same, but now the fibers which were loaded in compression before you rotated it are now loaded in tension, and vice-versa. Thus if the shaft is rotated let us say at 900 revolutions per minute then the shaft is cyclically stressed 900 times a minute.

To illustrate how damaging such type load is, take a paper clip, bend it out straight, then pick a spot in the middle, and bend the clip 90° back and forth at that spot (from straight to "L" shaped and back). When you bend it the other way, you reverse the stresses (fully reversing fatigue). You can notice that the clip will break in a few to about a maximum of 10 cycles.

When you are bending it you are plastically-deforming the metal, you are, by definition, exceeding its yield stress. When you bend it in one direction, you are applying a high tensile stress to the fibers on one side of the OD, and a high compressive stress on the fibers on the opposite side. In the next cycle the phenomena is repeated, the tensile stress fibers are now compressed and vice versa, thus the material is cyclically strained which ultimately results in their premature failure.

Fatigue Failure

Often machine members subjected to such repeated or cyclic stressing are found to have failed even when the actual maximum stresses were below the ultimate strength of the material, and quite frequently at stress values even below the yield strength. The most distinguishing characteristics is that the failure had occurred only after the stresses have been repeated a very large number of times. Hence the failure is called fatigue failure.

ASTM Definition of fatigue

- The process of ***progressive localized permanent*** structural changes occurring in a material subjected to conditions that produce ***fluctuating stresses*** at some point or points and that may culminate in ***cracks*** or complete ***fracture*** after a sufficient number of fluctuations.

Let us first make an attempt to understand the basic mechanism of fatigue failure

Fatigue Failure- Mechanism

A fatigue failure begins with a small crack; the initial crack may be so minute and can not be detected. The crack usually develops at a point of localized stress concentration like discontinuity in the material, such as a change in cross section, a keyway or a hole. Once a crack is initiated, the stress concentration effect become greater and the crack propagates. Consequently the stressed area decreases in size, the stress increase in magnitude and the crack propagates more rapidly. Until finally, the remaining area is unable to sustain the load and the component fails suddenly. Thus fatigue loading results in sudden, unwarned failure.

Fatigue Failure Stages

Thus three stages are involved in fatigue failure namely

-Crack initiation

-Crack propagation

-Fracture

The macro mechanism of fatigue failure is briefly presented now.

Crack initiation

- Areas of localized stress concentrations such as fillets, notches, key ways, bolt holes and even scratches or tool marks are potential zones for crack initiation.
- Crack also generally originate from a geometrical discontinuity or metallurgical stress raiser like sites of inclusions
- As a result of the local stress concentrations at these locations, the induced stress goes above the yield strength (in normal ductile materials) and cyclic plastic straining results due to cyclic variations in the stresses. On a macro scale the average value of the induced stress might still be below the yield strength of the material.
- During plastic straining slip occurs and (dislocation movements) results in gliding of planes one over the other. During the cyclic stressing, slip saturation results which makes further plastic deformation difficult.

- As a consequence, intrusion and extrusion occurs creating a notch like discontinuity in the material.

Crack propagation

- This further increases the stress levels and the process continues, propagating the cracks across the grains or along the grain boundaries, slowly increasing the crack size.
- As the size of the crack increases the cross sectional area resisting the applied stress decreases and reaches a thresh hold level at which it is insufficient to resist the applied stress.

Final fracture

- As the area becomes too insufficient to resist the induced stresses any further a sudden fracture results in the component.

The micro mechanism of fatigue fracture

Cause

Material body **Cyclic stress**

Effect

Atomic → **Microscopic** → **Macroscopic**

Atomic

1.Dislocation movements

2.Dislocation multiplication

3.Defect interaction

4.Cross slip

Microscopic

1. Slip formation

2. Slip saturation

3. Structure deterioration

4. Extrusion intrusion

5. Engergy changes

6. Crack nucleation and growth

Crystallographically

Macroscopic

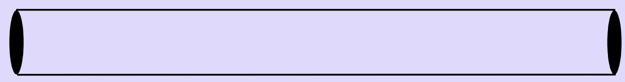
Crack propagation

1.Stable stages

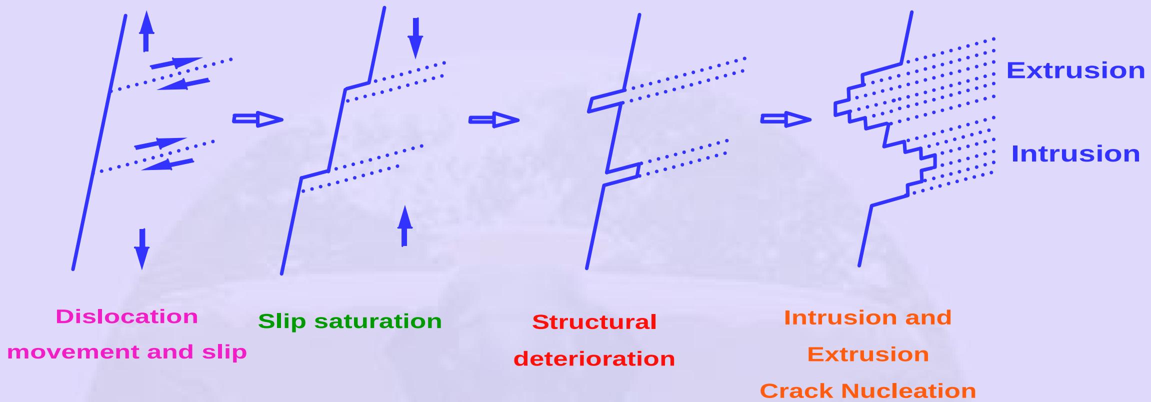
2.Unstable stages

3.Critical length

4.Final fracture



Variable stress in shaft under rotation

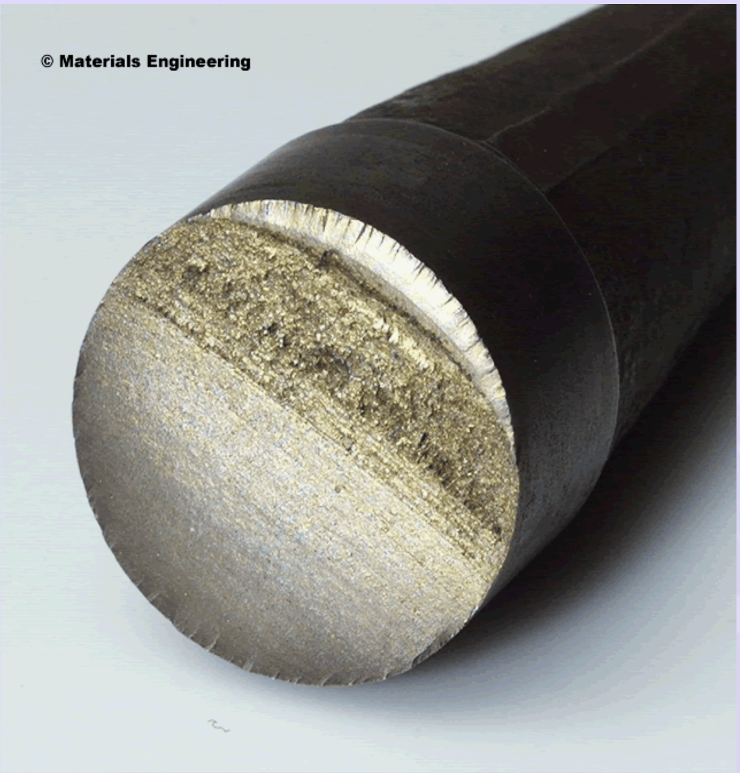


Effect of cyclic stressing

Animate

Basic features of failure appearance

- A fatigue failure, therefore, is characterized by two distinct regions. The first of these is due to progressive development of the crack, while the second is due to the sudden fracture. The zone of sudden fracture is very similar in appearance to the fracture of a brittle material, such as cast iron, that has failed in tension. The crack propagation zone could be distinguished from a polished appearance. A careful examination (by an experienced person) of the failed cross section could also reveal the site of crack origin


© Materials Engineering